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Effect of microbial consortia on vegetative growth of gladiolus (cv. Rose supreme) under Tarai region of Uttarakhand

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Abstract
The present experiment entitled Effect of microbial consortia on vegetative growth of gladiolus (cv. Rose supreme) under Tarai region of Uttarakhand was carried out at Modern Floriculture Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand during 2022-23 and 2023-24. Experiment was conducted in Factorial Randomized Block Design with an additional treatment having three replications. Four different concentrations of microbial consortia, *viz*., D_1 (3 mL L^{-1}), D_2 (6 mL L^{-1}), D_3 (9 mL L^{-1}) and D_4 (12 mL L^{-1}) of water, applied through three distinct methods *viz*., M_1 (Dipping of corms in consortia), M_2 (Application by mixing with vermicompost) and M_3 (Application of consortia through spray). During 2022-23 and 2023-24, among different methods application of mixing microbial consortia with vermicompost (M_2) was recorded superior with respect to different vegetative parameters like 50 per cent sprouting, plant height at 30 and 60 days, number of leaves at 30 and 60 days, length of longest leaf at 60 days, width of longest leaf at 60 days and number of tillers per corm at vegetative stage compared to other methods. Among different doses, higher doses of microbial consortia showed significantly better performance than lower doses.

Keywords: Microbial consortia, vegetative growth, *Gladiolus* cv. Rose Supreme, Tarai region, Uttarakhand, vermicompost, sprouting, plant height, tillers

Introduction

Flowers are nature's beloved gift to mankind and symbolize beauty, purity, peace and love. It is said that man is born with flowers, lives with flowers and finally dies with flowers. Gladiolus (*Gladiolus grandiflorus* L.) is one of the most commercially important cut flowers, valued for its magnificent spikes, wide range of vibrant colours and long vase life. It is a flower of glamour and perfection and known as the 'queen of bulbous flower' due to its flower spikes with florets of massive forms, attractive shapes, elegant, dazzling and delicate florets besides the excellent vase life. Gladiolus is grown on flower bed in gardens and used in floral arrangements for interior decoration as well as making high quality bouquets (Lepcha *et al.*, 2007) [24]. Belonging to the family Iridaceae and native to South Africa, gladiolus occupies a prime position in the global floriculture trade due to its aesthetic appeal and versatility in landscape use as well as floral arrangements.

The name gladiolus was originally derived by Pliny the Elder (23-79 AD), from the Latin word *gladiolus*, meaning 'sword' since the leaves of gladiolus resemble the sword so that commonly known as 'Sword lily' (Salunkhe *et al.*, 1990) [34]. In European country, it was called as "Corn Flag" because *Gladiolus illyricus* found as a weed in the cornfield (Kumar *et al.*, 2007; Singh *et al.*, 2008) [23, 36]. In India, floriculture occupies an area of approximately 297 thousand hectares, yielding about 3,231 thousand metric tonnes of floricultural produce annually. Among the various ornamental crops, gladiolus holds a significant share, covering about 11.74 thousand hectares with an annual production of 180.88 thousand metric tonnes of spikes. In Uttarakhand, gladiolus cultivation is steadily expanding, with an estimated area of 57.51 hectares, producing nearly 91.58 lakh spikes (Anonymous, 2023) [3]. Microbial consortium is a group of two or more different microorganisms that interact and function together as a community. It is a single carrier based microbial product that contains N fixing,

P and Zn solubilising and plant growth promoting microbes.
In agriculture, the use of multiple microorganisms has received attention due to their capacity to provide ecological functions, including soil bioremediation (Rajpal *et al*., 2022) [29], plant growth promotion (Chen *et al*., 2021; Kaur *et al*., 2022) [10, 20] and pest and disease suppression (Nafady *et al*., 2022; Soth *et al*., 2022) [26, 37].
In recent years, the use of microbial consortia, a synergistic blend of beneficial microorganisms such as *Rhizobium* and plant growth-promoting rhizobacteria (PGPR) has gained attention as a sustainable alternative to a sole place of chemical fertilization. *Rhizobium*, traditionally associated with nitrogen fixation in legumes, has been reported to produce growth hormones and improve nutrient uptake even in non-leguminous crops through associative symbiosis (Dent *et al*., 2017) [13].
PGPR on the other hand, enhance plant growth via multiple mechanisms such as solubilizing phosphorus, producing phytohormones (IAA, gibberellins, cytokinins) and inducing systemic resistance against pathogens (Diaz-Valle *et al*., 2019) [14]. When applied in combination, these microbes can exert complementary effects, improving root architecture, nutrient acquisition and photosynthetic efficiency, thereby promoting the overall vegetative growth of plant. Recognizing the benefits of these microorganisms in the area of floriculture especially in gladiolus cultivation as well as limited scientific evidence on the response of integrated microbial consortia on gladiolus under *Tarai* region of Uttarakhand provided the purpose to conduct this study. The experimental finding offers a theoretical support and technical assistance for promote the sustainable growth of gladiolus cultivation

Materials and Methods

Experimental site: The experiment was carried out at the Model Floriculture Centre of the G.B. Pant University of Agriculture and Technology, Pantnagar, District Udham Singh Nagar (Uttarakhand), during the year 2022-23 and 2023-24 from October to April months. The experimental site is located in the *Tarai* region of Uttarakhand and comes under mollisols.

Experimental material and details: The corms of gladiolus variety "Rose Supreme" was used as experimental material for the study. The experiment was performed in Factorial Randomized Block Design with an additional treatment.
There were total thirteen treatment combinations with 3 replications under open field conditions. The treatment combinations includes: Four concentrations of microbial consortia (*Rhizobium* x plant growth promoting rhizobacteria i.e. LR-35-01 x KB-133), namely D_1 (3 mL L^{-1}), D_2 (6 mL L^{-1}), D_3 (9 mL L^{-1}) and D_4 (12 mL L^{-1}) of water, applied through three distinct methods. In the first method (M_1), corms were immersed in the microbial consortia solution for 15 minutes, shade-dried and then planted. In the second method (M_2), the microbial consortia were thoroughly mixed with vermicompost and incubated for 48 hours prior to planting and then mixture was applied around the corms at the time of planting. In the third method (M_3), the consortia solution was applied through spray in two split doses i.e. half at the 3 leaf stage and the remaining half at the 6 leaf stage. Cultural operations like earthing up, staking, weeding and irrigation were done as per the crop requirement.

Observation recorded: Observations such as days taken to 50 per cent sprouting, plant height at 30 and 60 days, number of leaves at 30 and 60 days, length of longest leaf at 60 days, width of longest leaf at 60 days and number of tillers per corm were taken at vegetative stage.

Results and Discussion

1. Days taken to 50 per cent sprouting

Data pertain to days taken to 50 per cent sprouting is presented in table 1 and graphically illustrated in figure 1. Among the methods of application, during 2022-23, the minimum number of days to 50% sprouting (10.50 days) was recorded in application by mixing microbial consortia with vermicompost (M_2), which was significantly earlier than dipping of corms in consortia (M_1: 12.33 days) and application of consortia through spray (M_3: 13.42 days). A similar trend was observed in 2023-24, whereas in M_2 again resulted in the earliest sprouting (10.50 days), followed by M_1 (12.08 days), while M_3 took the maximum time (13.50 days). The pooled mean also confirmed the superiority of M_2 (10.50 days) in promoting early sprouting, while M_3 was consistently the slowest (13.46 days). With respect to doses, the differences among D_1 (3 mL L^{-1}), D_2 (6 mL L^{-1}), D_3 (9 mL L^{-1}) and D_4 (12 mL L^{-1}) were statistically non-significant in both years as well as in the pooled mean, indicating that within the tested range, dose variation did not markedly affect sprouting time. However, numerically shortest duration was noted with D_3 (11.89 days), closely followed by D_4 (11.94 days), while D_1 took slightly longer (12.39 days). When comparing control with the rest of the treatments, a significant reduction in the number of days to 50% sprouting was observed in the treated plots. The control recorded 13.67 and 14.00 days in 2022-23 and 2023-24, respectively (pooled mean- 13.83 days), whereas the rest of the treatments averaged 12.08 and 12.03 days (pooled mean- 12.06 days), indicating that microbial consortia application accelerated sprouting by approximately 1.77 days over the untreated control. The application of microbial consortia improves root architecture and nutrient uptake, which enhances meristematic activity at corm base and stimulates bud growth. This rapid sprouting can be attributed to the phytohormonal action (like IAA, gibberellins, etc.) produced by these isolates, which enhances starch mobilization by up-regulating amylase activity in dormant corms, thus increases availability of soluble sugars and trigger earlier bud emergence (Sun *et al*., 2019) [39].The results also suggest that combining microbial consortia with vermicompost (M_2) may have a synergistic effect that accelerates sprouting, possibly due to enhanced microbial activity in the rhizosphere, improving nutrient availability and absorption by the corms (Ravindran *et al*., 2016) [30] with gradual release of bioactive metabolites around the corms (Rekha *et al*., 2018) [32]. Similar results were reported by Bajpai *et al*. (2022) [6], Karagoz *et al*. (2019) [19] and Akter *et al*. (2017) [1] in gladiolus, Jitendra Kumar *et al.* (2011) [18] and Hadwani *et al.* (2013) [16] in tuberose.

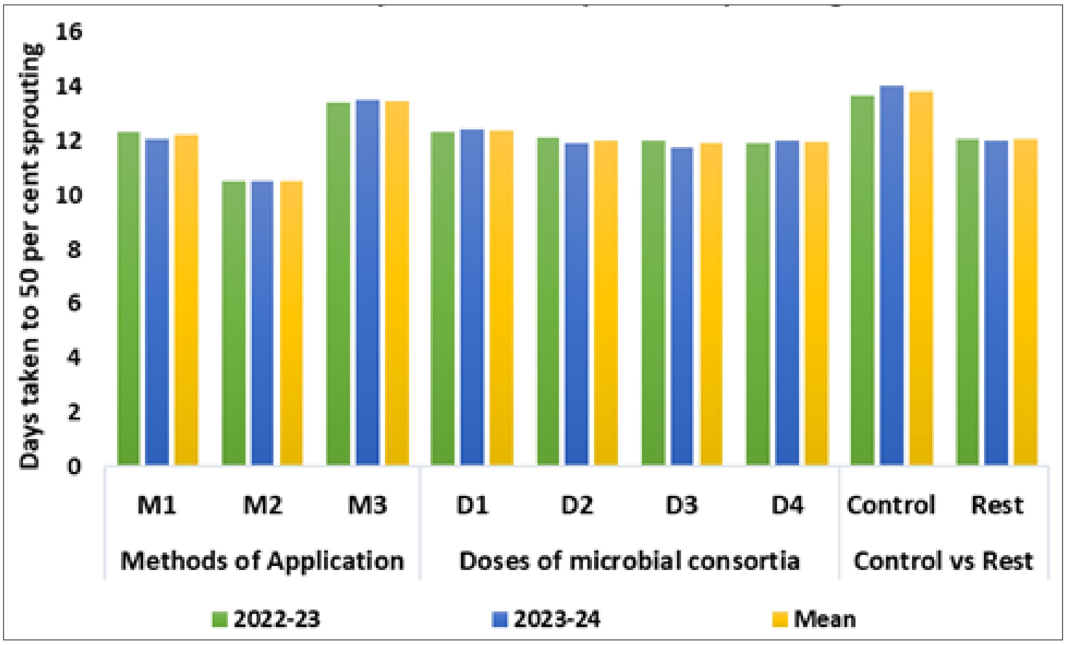

Fig 1: Effect of microbial consortia on days taken to 50 per cent sprouting

2. Plant height at 30 days

Observation regarding plant height at 30 days is presented in table 1 and graphically illustrated in figure 2. In the 1st Year (2022-23), among methods of application, the highest plant height (47.37 cm) at 30 days was recorded in mixing microbial consortia with vermicompost (M_2), which was significantly higher than both dipping of corms in consortia (M_1) and application of consortia through spray (M_3) having plant height 42.14 and 40.03 cm, respectively. Similarly, in 2nd year (2023-24) maximum plant height of 52.16 cm was recorded in (M_2) followed by 44.77 cm in M_1, however M_3 showed the lowest plant height of 41.30 cm. Pooled data also showed that mixing microbial consortia with vermicompost (M_2) consistently resulted in the highest plant height of 49.76 cm, which was significantly higher than both dipping of corms in consortia (M_1) at 43.45 cm and application of consortia through spray (M_3) at 40.66 cm. Among different doses of microbial consortia, D_3 (9 mL/L) recorded the highest plant height of 44.49 and 47.78 cm (pooled mean: 46.14 cm), which was followed by D_4 (12 mL/L) at 43.15 and 46.54 cm (pooled mean: 44.85 cm) and D_2 (6 mL/L) at 42.86 and 45.85 cm (pooled mean: 44.35 cm), while the lowest plant height 42.21 and 44.13 cm (pooled mean: 43.17 cm) was observed in D_1 (3 mL/L) in both the year 2022-23 and 2023-24, respectively. A non-significant differences between the doses, indicates that all doses provided similar growth responses, with a slight trend towards higher plant height at the middle and higher doses (9-12 mL/L). Among the control vs rest, the treated plants (including all methods and doses) in both year (2022-23 and 2023-24) had a significantly higher plant height of 43.18 and 46.08 cm compared to the control plants, having 39.82 and 40.97cm of height, respectively. In mean data, comparing control and treated plants, the treated plants (all methods and doses) showed a significantly higher plant height of 44.63 cm compared to the control plants, which had a height of 40.40 cm.

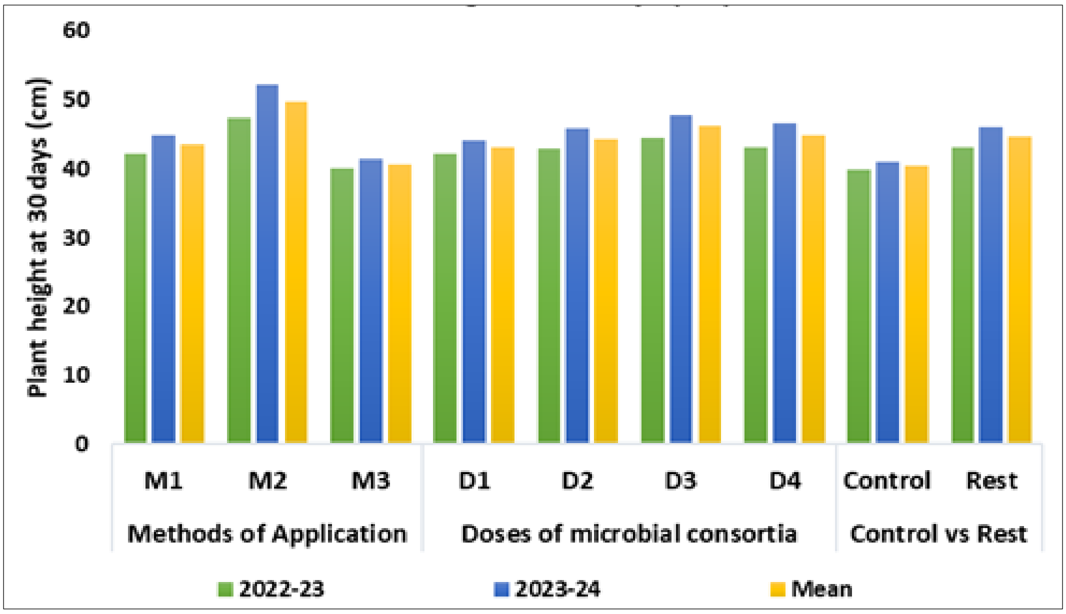

Fig 2: Effect of microbial consortia on plant height at 30 days

3. Plant height at 60 days

Data with respect to plant height at 30 days is represented in table 1 and graphically illustrated in figure 3. Among the methods of application, during 2022-23, maximum plant height (70.43 cm) was observed with application by mixing microbial consortia with vermicompost (M_2), significantly taller than dipping of corms in consortia (M_1 i.e. 64.57 cm) and application of consortia through spray (M_3 i.e. 56.17 cm). A similar trend was recorded in 2023-24, where M_2 again attained the maximum height (74.36 cm), followed by M_1 (69.56 cm), while M_3 remained the lowest (60.69 cm). The pooled mean also indicated the superiority of M_2 (72.39 cm) over M_1 (67.07 cm) and M_3 (58.43 cm), suggesting that incorporation of microbial consortia with vermicompost consistently enhanced vegetative vigour. Regarding the doses, during 2022-23, the tallest plants were obtained with D_3 (9 mL L^{-1}), recording 67.15 cm, which was significantly higher than D_1 (59.96 cm) and D_2 (63.21 cm) and statistically at par with D_4 (64.58 cm). In 2023-24, D_3 again maintained its superiority with 71.67 cm which is statistically at par with D_4 (70.58 cm), while minimum plant height was recorded in D_1 (63.08 cm) which is statistically at par with D_2 (67.49 cm). The pooled mean confirmed this trend, with D_3 (69.41 cm) producing the tallest plants, which is statistically at par with D_4 (67.58 cm), while the minimum height was recorded in D_1 (61.52 cm). In the comparison between control and rest of the treatments, a pronounced and significant increase in plant height was recorded with microbial consortia application. The control recorded only 50.49 and 52.57 cm during 2022-23 and 2023-24, respectively (pooled mean: 51.53 cm), whereas the treated plots averaged 63.73 cm and 68.20 cm in 2022-23 and 2023-24, respectively (pooled mean: 65.97 cm), representing an increase of 27.99% over the untreated control.

The superior performance with respect to improved plant height with application of mixing microbial consortia and vermicompost (M_2) can be attributed to the combined effect of microbial inoculation with nutrient-rich medium (vermicompost), where microbes enhance nutrient availability, their mobilization (particularly nitrogen and phosphorus) and production of phytohormones such as indole-3-acetic acid and gibberellic acid, while vermicompost improves soil structure and fertility, providing sustained benefits throughout the plant's growth cycle (Choi *et al*., 2024) [11]. This leads to better root and shoot development, which promote cell elongation and resulting into taller plants. The highest plant height was observed with D_3 (9 mL/L), suggesting that this dose optimizes microbial activity without overwhelming the growth and development of plant. The data presented in the experiment was supported by the findings of Srivastava *et al*. (2005) [38], Ali *et al.* (2014) [2] and Baskaran *et al.* (2014) [8] in gladiolus.

Table 1: Effect of microbial consortia (LR-35-01 x KB-133 i.e. *Rhizobium* x PGPR) on days taken to 50 percent sprouting and plant height at 30 and 60 days

Treatments	Days taken to 50 per cent sprouting			Plant height at 30 days			Plant height at 60 days		
	2022-2023	2023-2024	Mean	2022-2023	2023-2024	Mean	2022-2023	2023-2024	Mean
Factor 1 Method of Application (M)									
M_1 (Dipping of corms in consortia)	12.33	12.08	12.21	42.14	44.77	43.45	64.57	69.56	67.07
M_2 (Application by mixing with vermicompost)	10.50	10.50	10.50	47.37	52.16	49.76	70.43	74.36	72.39
M_3 (Application of consortia through spray)	13.42	13.50	13.46	40.03	41.30	40.66	56.17	60.69	58.43
SE(m)±	0.263	0.243	0.176	0.744	1.177	0.676	1.452	1.622	0.850
C.D. at (5%)	0.769	0.708	0.514	2.172	3.436	1.973	4.238	4.735	2.481
Factor 2 Doses of microbial consortia (D)									
D_1 (3mL/L)	12.33	12.44	12.39	42.21	44.13	43.17	59.96	63.08	61.52
D_2 (6mL/L)	12.11	11.89	12.00	42.86	45.85	44.35	63.21	67.49	65.35
D_3 (9mL/L)	12.00	11.78	11.89	44.49	47.78	46.14	67.15	71.67	69.41
D_4 (12mL/L)	11.89	12.00	11.94	43.15	46.54	44.85	64.58	70.58	67.58
SE(m)±	0.304	0.280	0.204	0.859	1.372	0.781	1.676	1.873	0.981
C.D. at (5%)	NS	NS	NS	NS	NS	NS	4.893	5.467	2.864
Control vs Rest									
Control	13.67	14.00	13.83	39.82	40.97	40.40	50.49	52.57	51.53
Rest	12.08	12.03	12.06	43.18	46.08	44.63	63.73	68.20	65.97
SE(d)±	0.548	0.505	0.367	1.549	2.474	1.407	3.022	3.377	1.769
C.D. at (5%)	1.132	1.042	0.757	3.197	5.106	2.905	6.237	6.969	3.651

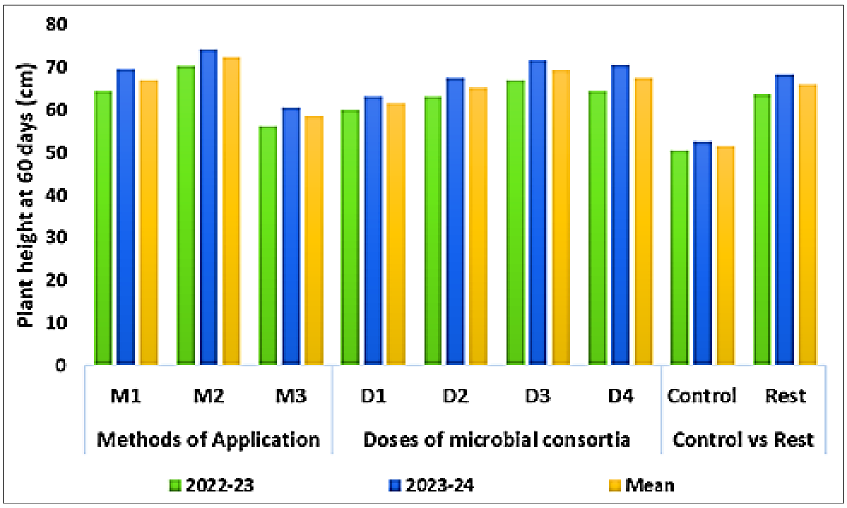

Fig 3: Effect of Microbial Consortia on plant height at 60 days

4. Number of leaves at 30 days

The data regarding number of leaves at 30 days presented in table 2 and graphically illustrated in figure 4. In the first year (2022-23), among the methods of application, the highest number of leaves (5.36) was recorded in application by mixing microbial consortia with vermicompost (M_2), which was significantly higher than other methods. However, lowest number of leaves (3.93) was observed in application of consortia through spray (M_3) with an intermediate number of leaves (4.65) in dipping of corms in consortia (M_1). In the second year (2023-24), again the highest number of leaves (5.95) was observed in M_2, significantly outperforming M_1 (5.19) and M_3 (4.44). Similarly, in mean data over both years, indicated that mixing with vermicompost (M_2) resulted in the highest mean number of leaves (5.65), which was significantly greater than M_1 (4.92) and M_3 (4.18). Regarding the doses of microbial consortia, no significant difference was observed among doses but the number of leaves increased with increasing doses in both the years, with the maximum number of leaves i.e. 4.89 and 5.43 leaves (pooled mean: 5.16) recorded at D_3 (9 mL/L), closely followed by D_4 (12 mL/L) with 4.77 and 5.11 leaves (pooled mean: 4.94). However, the lowest number of leaves i.e. 4.43 was reported at D_2 (6 mL/L) in first year and 4.93 at D_1 (3 mL/L) in the second year. In mean data, dose D_3 (9 mL/L) resulted in the maximum number of leaves (5.16), which was statistically at par with D_4 (4.94). For the control v/s rest comparison in both the year and pooled mean, treated plants (all methods and doses) had a significantly higher number of leaves i.e. 4.65 and 5.19 (pooled mean: 4.92) compared to the control plants i.e. 3.69 and 4.00 with pooled mean of 3.84 leaves, which did not receive any microbial consortia treatment. This clearly indicates the positive effect of microbial inoculation on leaf production.

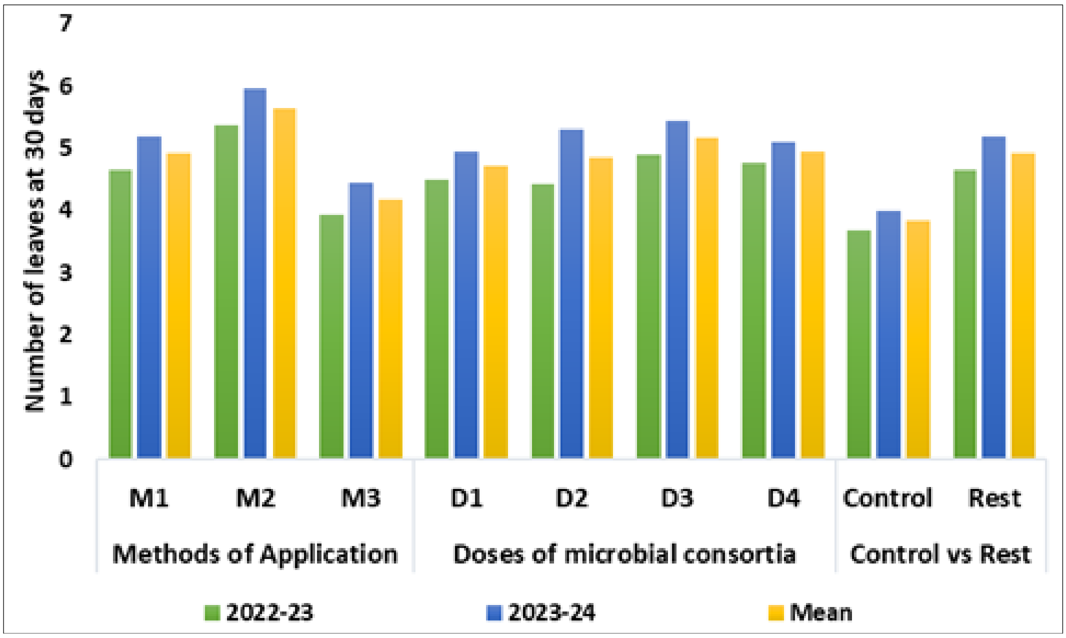

Fig 4: Effect of Microbial Consortia on number of leaves at 30 days

5. Number of leaves at 60 days

The data pertaining to the effect of microbial consortia on the number of leaves per plant at 60 days after planting, as influenced by different methods and doses of microbial consortia during 2022-23 and 2023-24 with mean data presented in table 2 and graphically illustrated in figure 5. The differences were statistically significant among methods and doses during both the years as well as in the pooled mean. Among the methods of application, during 2022-23, the highest number of leaves (11.67 leaves) was recorded in M_2 (application by mixing microbial consortia with vermicompost), which was significantly higher than M_1 (10.14 leaves) and M_3 (10.18 leaves). A similar trend was observed in 2023-24, where M_2 again maintained its superiority with 11.50 leaves, followed by M_1 (10.50 leaves) and M_3 (10.22 leaves). The pooled mean confirmed the consistent superiority of M_2 (11.59 leaves), while M_3 remained the lowest (10.20 leaves). With respect to the doses, during 2022-23 and 2023-24, the maximum number of 11.19 and 11.41 leaves (pooled mean: 11.30 leaves) was observed in D_3 (9 mL L^{-1}), which was statistically at par with D_4 having 11.03 and 10.93 leaves (pooled mean: 10.98 leaves), whereas minimum number of leaves i.e. 9.84 and 10.00 (pooled mean: 9.92 leaves) were found in D_1. When comparing the control with the rest of the treatments, a marked and significant increase in the number of leaves was recorded with microbial consortia application. The control recorded only 8.11 and 8.22 leaves during 2022-23 and 2023-24, respectively (pooled mean- 8.17), whereas the treated plots averaged 10.66 and 10.74 leaves (pooled mean: 10.70), indicating an increase of about 31% over the untreated control.

Enhanced early leaf development in gladiolus cv. Rose Supreme with combined use of vermicompost and microbial consortia may be due to act of vermicompost as a nutrient reservoir, supporting beneficial microbial populations, which promote better root development and nutrient uptake, thereby stimulating leaf growth (Singh *et al*., 2020) [35]. Although the effect of different doses was statistically non-significant at 30 days and significant at 60 days, but better leaf growth noted with higher doses may be due to higher microbial populations facilitating nutrient solubilization and plant hormone production. The improvement in leaf number with microbial treatments can be attributed to enhanced nutrient availability, production of growth-promoting substances like vitamins and enzymes and better overall plant vigor (Banasiak *et al*., 2021) [7]. These findings are consistent with previous studies by Dalvi *et al*. (2009) [12], Pandey *et al*. (2013) [27] and Baskaran *et al*. (2014) [8] in Gladiolus, Chaudhary *et al*. (2007) [9] in Tuberose and Patel *et al*. (2017) [28] in Rose, who reported positive effects of microbial inoculation on leaf and other vegetative growth parameters.

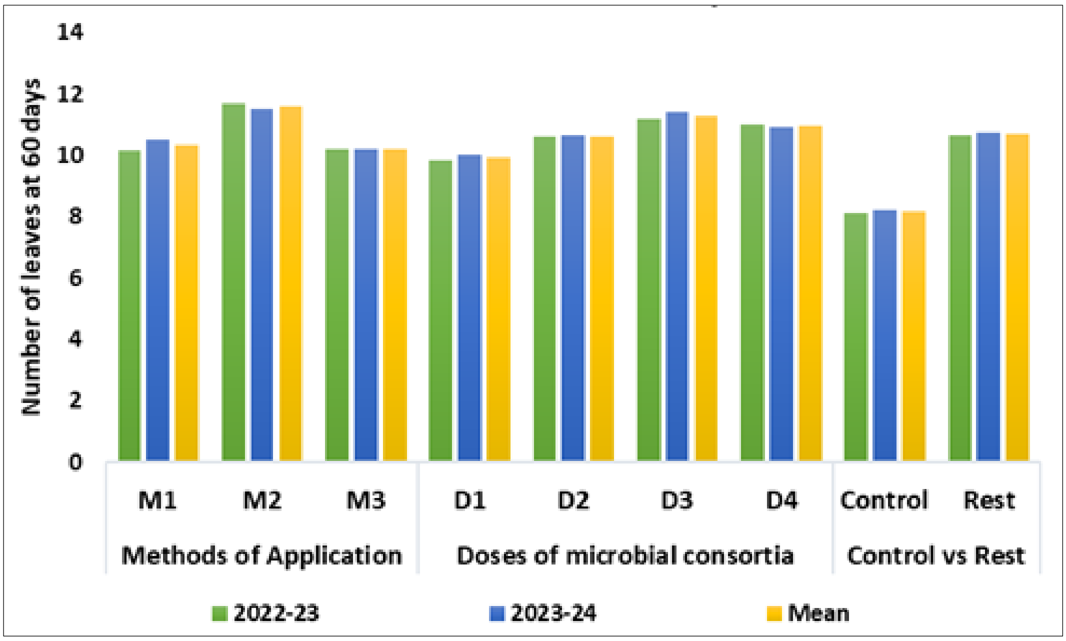

Fig 5: Effect of microbial consortia on number of leaves at 60 days

Table 2: Effect of microbial consortia (LR-35-01 x KB-133 i.e. *Rhizobium* x PGPR) on number of leaves at 30 and 60 days

Treatments	Number of leaves at 30 days			Number of leaves at 60 days		
	2022-2023	2023-2024	Mean	2022-2023	2023-2024	Mean
Factor 1 Method of Application (M)						
M_1 (Dipping of corms in consortia)	4.65	5.19	4.92	10.14	10.50	10.32
M_2 (Application by mixing with vermicompost)	5.36	5.95	5.65	11.67	11.50	11.59
M_3 (Application of consortia through spray)	3.93	4.44	4.18	10.18	10.22	10.20
SE(m)±	0.122	0.129	0.091	0.201	0.274	0.156
C.D. at (5%)	0.355	0.378	0.265	0.587	0.800	0.455
Factor 2 Doses of microbial consortia (D)						
D_1 (3mL/L)	4.50	4.93	4.71	9.84	10.00	9.92
D_2 (6mL/L)	4.43	5.30	4.86	10.60	10.63	10.62
D_3 (9mL/L)	4.89	5.43	5.16	11.19	11.41	11.30
D_4 (12mL/L)	4.77	5.11	4.94	11.03	10.93	10.98
SE(m±)	0.140	0.149	0.105	0.232	0.316	0.180
C.D. at (5%)	NS	NS	0.306	0.678	0.923	0.526
Control vs Rest						
Control	3.69	4.00	3.84	8.11	8.22	8.17
Rest	4.65	5.19	4.92	10.66	10.74	10.70
SEm±	0.253	0.269	0.189	0.419	0.570	0.325
C.D. at (5%)	0.522	0.556	0.390	0.865	1.177	0.670

6. Number of tillers per corm

The data pertaining to the number of tillers per corm are presented in table 3 and figure 6. In the first year (2022-23), among the methods of application, the highest number of tillers per corm (2.11 tillers) was recorded in application by mixing microbial consortia with vermicompost (M_2), which was significantly higher than the other two methods. The lowest number of tillers (1.72 tillers) was observed in application of consortia through spray (M_3). During second year (2023-24), M_2 again recorded the highest number of tillers (2.64 tillers), significantly outperforming M_1 and M_3, having 2.06 and 1.86 tillers per corm, respectively. The mean data confirmed these findings, with M_2 method showing the highest mean number of tillers per corm (2.37 tillers), significantly higher than M_1 (1.97 tillers) and M_3 (1.79 tillers) indicating that mixing microbial consortia with vermicompost enhances tiller development possibly due to better microbial colonization and sustained nutrient release in the root zone, however soil-based application methods are more effective for tiller induction than application of consortia through spray. The number of tillers was also significantly influenced by different doses of microbial consortia. In both the year (2022-23 and 2023-24, respectively), maximum number of 2.15 and 2.52 tillers (pooled mean: 2.33 tillers) was recorded at D_3 (9 mL/L), which was statistically at par with 1.96 and 2.37 tillers (2.17 tillers) in D_4, 12 mL/L and significantly higher than the lowest dose (D_1, 3 mL/L) that produced 1.59 and 1.74 tillers (pooled mean: 1.67 tillers) per corm. This dose-dependent increase suggests that moderate concentrations of microbial consortia enhance tillering, possibly through improved nutrient uptake and hormonal stimulation. Comparing control and treated plants (2022-23), the treated group (all methods and doses) produced a significantly higher number of tillers (1.91) compared to the control (1.44). Similarly, in second year (2023-24) control noted least tiller number (1.33 tillers) compared to treated plants (2.18 tillers). In mean data treated plants overall had significantly higher tiller numbers (2.05 tillers) compared to the control (1.39 tillers) demonstrating the overall positive effect of microbial consortia on tiller production.

Significantly improved tiller production, with M_2 suggests that combining microbial consortia with a nutrient-rich carrier like vermicompost enhances microbial activity and nutrient availability in the root zone, promoting better tiller initiation and growth (Choi *et al.*, 2024) [11]. This enhanced microbial activity facilitates improved nutrient mineralization and mobilization, increasing the availability of essential macro- and micronutrients that are vital for tiller initiation and growth (Reed and Glick, 2023) [31]. Additionally, microbial consortia can synthesize various plant growth-promoting substances, including phytohormones, which promote cell division and elongation in the shoot apical meristem, directly stimulating the formation of additional tillers (Kende and Zeevaart, 1997) [21]. When applied with vermicompost, the sustained release of nutrients and hormones from both provides continuous stimulation throughout the critical stages of corm growth, leading to enhanced tiller number. Better tiller production with application through spray (M_3) compared to dipping (M_1) in some cases, but less effective than mixing with vermicompost likely due to limited root zone benefits. However, application through spray may improve physiological functions such as photosynthesis or disease resistance to some extent (Fageria *et al.*, 2009; Atteya *et al.*, 2022) [15, 5], but they do not directly enhance root microbial populations or nutrient uptake. The enhanced microbial activity at the optimal dose improves nutrient cycling, leading to better nutrient uptake by the plants. This includes increased availability of phosphorus through solubilization of insoluble phosphates and enhanced nitrogen availability by biological fixation (Iftikhar *et al.*, 2024; Khan *et al.*, 2024; Rios-Ruiz *et al.*, 2024) [17, 22, 33].

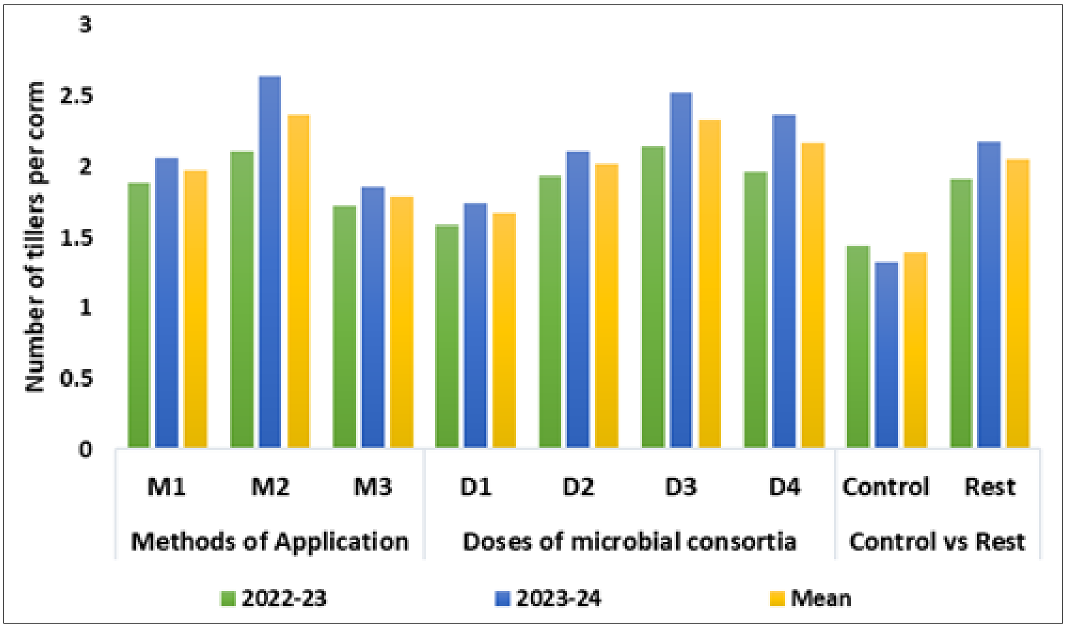

Fig 6: Effect of microbial consortia on number of tillers per corm

7. Length of longest leaf at 60 days

Length of the longest leaf at 60 days showing significant difference for different methods and doses presented in table 3 and graphically illustrated in figure 7. Among the methods of application, the longest leaf length (44.33 cm) was recorded in application by mixing microbial consortia with vermicompost (M_2), with shortest leaf length (40.42 cm) in dipping the corms in consortia (M_1), while application of consortia through spray (M_3) resulted in an intermediate length of 40.50 cm during the first year (2022-23). Similarly, in the second year (2023-24), the longest leaf length (47.99 cm) was again recorded with M_2, significantly outperforming the M_1 at 40.96 cm and M_3 at 39.11 cm. The mean data analysis further confirmed the significant effect of the method of application and doses on leaf length. The highest mean leaf length (46.08 cm) was obtained with M_2, significantly higher than M_1 (40.73 cm) and M_3 (39.72 cm). The superior performance of M_2 indicates that incorporating microbial consortia with vermicompost provides a sustained release of nutrients and beneficial microbes, promoting better leaf growth. Among different doses in both the year (2022-23 and 2023-24, respectively), the maximum leaf length of 43.74 and 44.53 cm (pooled mean: 43.97 cm) was observed at the 9 mL/L dose (D_3), which was statistically at par with the 12 mL/L dose (D_4) where leaf length was 42.52 and 43.60 cm (pooled mean: 43.00 cm). The minimum leaf length of 39.94 and 40.57 cm (pooled mean: 40.42 cm) was recorded with lowest dose, 3 mL/L (D_1). In case of control versus treated plants in 2022-23 and 2023-24, the treated plants (all methods and doses combined) had a significantly higher leaf length (41.75 and 42.69 cm, respectively) compared to the control plants (35.02 and 36.60cm, respectively). In mean data control plants again showed the lowest mean leaf length of 35.57 cm, while treated plants averaged 42.18 cm, highlighting the beneficial impact of microbial consortia treatment on leaf growth.

The enhancement in leaf length with microbial consortia especially when integrated into vermicompost (M_2) can be attributed to synergistic effects of *Rhizobium* and PGPR, which improve rhizosphere microbial diversity, nitrogen fixation, phosphorus solubilization and production of growth-promoting hormones like vitamins, enzymes and phytohormones (Singh *et al.*, 2020) [35] and enhanced photosynthate accumulation. Vermicompost serves as a slow-release nutrient medium while also harboring beneficial microbes, leading to sustained nutrient availability (Choi *et al.*, 2024) [11] and enhanced root development, which supports longer leaf growth (Arancon *et al*., 2006) [4]. The dipping method (M_1) showed the least effect, likely due to limited duration of microbial contact with the plant. The optimal dose of 9 mL/L suggests that microbial activity and associated growth promotion peak at this concentration, with no significant advantage at higher doses.

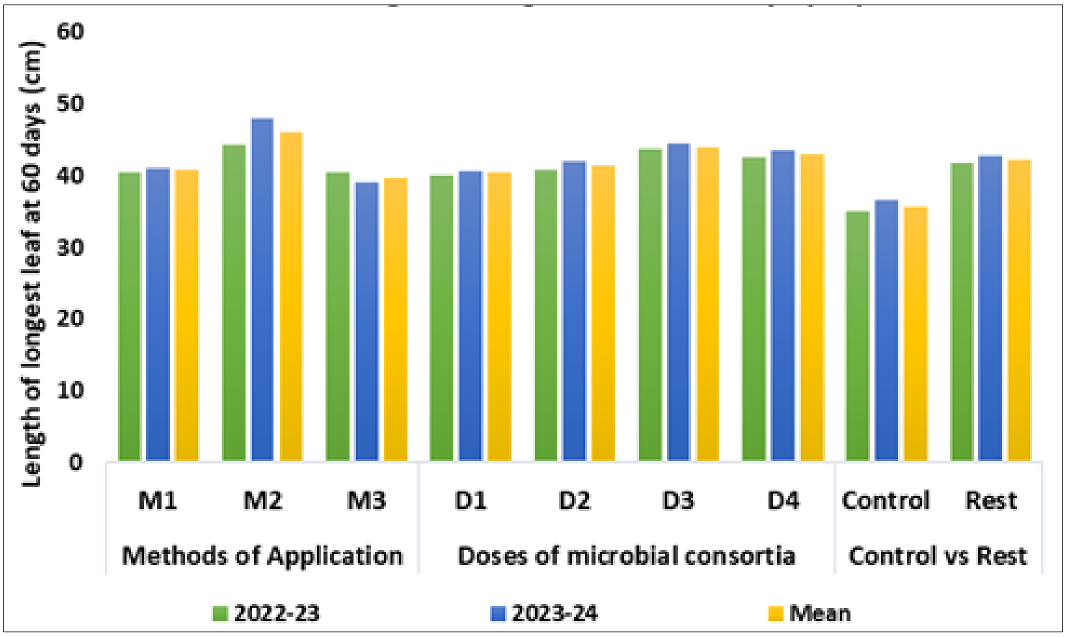

Fig 7: Effect of microbial Consortia on Length of longest leaf at 60 days

8. Width of longest leaf at 60 days

The data pertaining to width of the longest leaf at 60 days are presented in table 3 and figure 8. Statistically significant differences were noted among methods and doses during both the years as well as in the pooled mean. In the first year (2022-23), maximum leaf width (32.82 mm) was recorded in application by mixing microbial consortia with vermicompost (M_2), which was statistically at par with application of consortia through spray (M_3) with a leaf width of 31.77 mm, whereas minimum width of leaf (26.71 mm) was found in dipping of corms in consortia (M_1). In the second year (2023-24), the pattern remained consistent with the previous year. M_2 again recorded the maximum leaf width of 33.61 mm, followed by M_3 with 31.17 mm, while the minimum leaf width was found in M_1 (27.40 mm), indicating the limited effectiveness of corm dipping in promoting sustained foliar growth. In the mean data across both years, M_2 showed the maximum width of the longest leaf (33.22 mm), significantly outperforming M_3 (31.01 mm) and M_1 (27.05 mm), indicating the robustness of this method in enhancing foliar parameters. Among the different doses of microbial consortia in both the year, the maximum width of 32.91 and 33.05 mm (pooled mean: 32.42 mm) was observed in D_3 (9 mL/L), followed by D_4 (12 mL/L) recording 30.74 and 31.63 mm (pooled mean: 31.18 mm), respectively. These doses were significantly superior to D_2 (6 mL/L) at 29.83 and 30.33 mm (pooled mean: 30.08 mm), respectively. The minimum width of 28.25 and 27.89 mm (pooled mean: 28.01 mm) was observed in D_1 (3 mL/L), suggested that a moderate to high concentration of microbial consortia supports better leaf development. When comparing control versus treated plants (control vs rest), a significant increase in the width of the longest leaf was observed in treated plants across both years as well as in their mean. In 2022-23, treated plants had an average width of 30.43 mm, significantly higher than control (23.10 mm). The trend remained consistent in 2023-24, with treated plants showing 30.72 mm compared to 23.78 mm in control. The pooled mean followed a similar pattern (30.43 mm in treated vs. 22.94 mm in control), indicating the positive impact of microbial consortia across methods and doses.

The improved leaf width under higher microbial doses (notably D_3 and D_4) could be attributed to better microbial colonization and nutrient cycling in the rhizosphere, which promotes enhanced vegetative growth (Morales-Cedeno *et al*., 2021) [25]. Dipping method (M_1), despite being an early-stage treatment, lacks continued microbial support, while M_3, although better than M_1, but less effective than M_2 due to limited root-zone impact. The comparatively lower performance of M_1 might be attributed to the limited duration of microbial contact and rapid wash-off, reducing long-term microbial benefits. The main effect of microbial consortia is to induce physiological responses in the treated plants and most of these responses are able to affect plant metabolism, growth and development (Wally *et al*. 2013) [40].

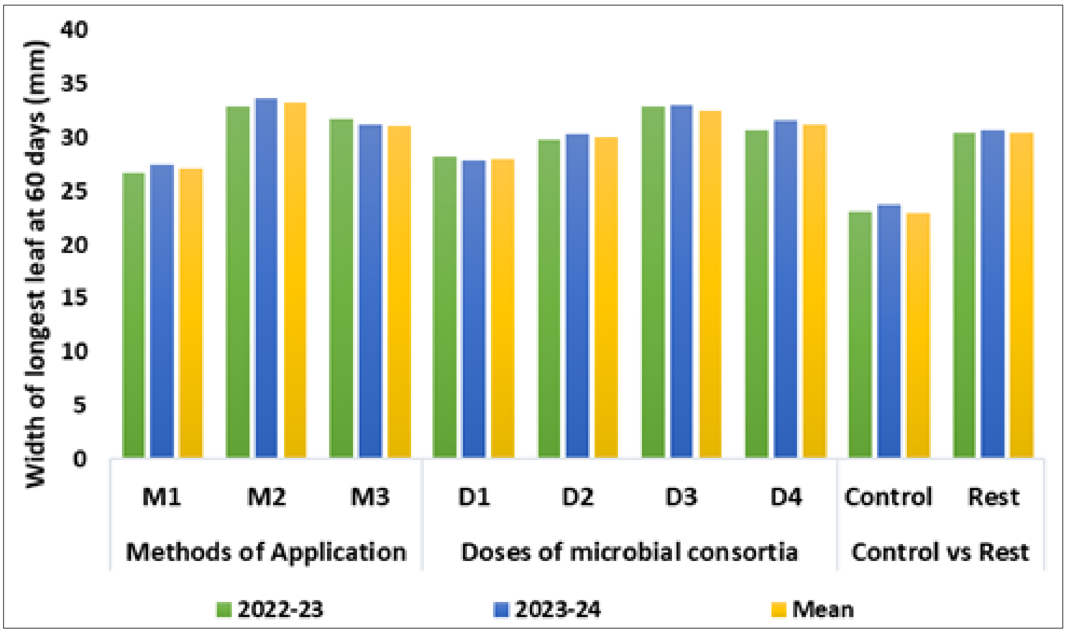

Fig 8: Effect of microbial consortia on width of longest leaf at 60 days

Table 3: Effect of microbial consortia (LR-35-01 x KB-133 i.e. *Rhizobium* x PGPR) on number of tillers per corm, length and width of longest leaf at 60 days

Treatments	Number of tillers per corm			Length of longest leaf at 60 days			Width of longest leaf at 60 days		
	2022-2023	2023-2024	Mean	2022-2023	2023-2024	Mean	2022-2023	2023-2024	Mean
Factor 1 Method of Application (M)									
M_1 (Dipping of corms in consortia)	1.89	2.06	1.97	40.42	40.96	40.73	26.71	27.40	27.05
M_2 (Application by mixing with vermicompost)	2.11	2.64	2.37	44.33	47.99	46.08	32.82	33.61	33.22
M_3 (Application of consortia through spray)	1.72	1.86	1.79	40.50	39.11	39.72	31.77	31.17	31.01
SE(m)±	0.075	0.080	0.052	0.514	0.610	0.368	0.548	0.552	0.331
C.D. at (5%)	0.218	0.234	0.151	1.501	1.782	1.075	1.598	1.612	0.965
Factor 2 Doses of microbial consortia (D)									
D_1 (3mL/L)	1.59	1.74	1.67	39.94	40.57	40.42	28.25	27.89	28.01
D_2 (6mL/L)	1.93	2.11	2.02	40.81	42.05	41.32	29.83	30.33	30.08
D_3 (9mL/L)	2.15	2.52	2.33	43.74	44.53	43.97	32.91	33.05	32.42
D_4 (12mL/L)	1.96	2.37	2.17	42.52	43.60	43.00	30.74	31.63	31.18
SE(m)±	0.086	0.093	0.060	0.594	0.705	0.425	0.632	0.638	0.382
C.D. at (5%)	0.252	0.270	0.175	1.733	2.057	1.241	1.846	1.862	1.114
Control vs Rest									
Control	1.44	1.33	1.39	35.02	36.60	35.57	23.10	23.78	22.94
Rest	1.91	2.18	2.05	41.75	42.69	42.18	30.43	30.72	30.43
SE(d)±	0.155	0.167	0.108	1.071	1.271	0.767	1.140	1.150	0.688
C.D. at (5%)	0.321	0.345	0.222	2.210	2.622	1.582	2.353	2.373	1.420

Conclusion

The results of experiment revealed that among different methods application of mixing microbial consortia with vermicompost (M_2) positively accelerate different vegetative parameters like 50 per cent sprouting, plant height at 30 and 60 days, number of leaves at 30 and 60 days, length of longest leaf at 60 days, width of longest leaf at 60 days and number of tillers per corm at vegetative stage compared to other methods. Among different doses, higher doses of microbial consortia showed significantly better performance than lower doses. Conversely, the minimum values for all the vegetative parameters were observed in untreated corms (Control).

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